Phase One Development of the NPOESS Conical-scanning Microwave Imager/Sounder (CMIS)

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Abstract - **The Conical-scanning Microwave Imager/Sounder (CMIS) is a multi-band radiometer currently under development by the National Polar-orbiting Operational Satellite System (NPOESS) Integrated Program Office and Boeing Satellite Systems (BSS). The CMIS is the follow-on for the Defense Meteorological Satellite System (DMSP) SSMIS and SSM/I conical-scanning radiometers. Two teams in competition performed the CMIS phase one (risk reduction) development. At the end of this period, in July 2001, BSS was selected to continue development of the CMIS with the first flight unit delivery scheduled for 2005 and launch in 2009. The current baseline CMIS sensor design has several unique features including channels from ~6 GHz to above 190 GHz, sea surface wind direction capability, atmospheric temperature sounding up to ~0.01 mb using digital FFT channelization techniques, dual primary apertures, and moisture profiling channels. This paper will focus on the unique aspects of the CMIS baseline design and describe the link between sensor design and fulfillment of the assigned CMIS operational environmental data products.**

1. Introduction

Space-borne conical-scanning radiometers since the DMSP special-sensor microwave imager (SSM/I), have continued to evolve in complexity and size. In the near-future, several conical-scanning radiometers are scheduled for launch. They include the SSM/I follow-on Special Sensor Microwave Imager/Sounder (SSMIS) which will provide the first sounding measurements made with conical-scanning geometry, the Advanced Scanning Microwave Radiometer (AMSR) with an aperture exceeding 1 meter, and the first (spaceborne) polarimetric radiometer, WindSat. The CMIS, currently scheduled for completion in 2005, and launch ~2009, will essentially have the capabilities represented by each of these heritage radiometers in a single sensor.

2. CMIS Development

The current CMIS baseline design was developed over ~3.5 year risk reduction phase contract period from Aug 1997 to Feb 2001. The risk reduction phase was governed by the CMIS Sensor Requirements Document (SRD) developed by the Integrated Program Office (IPO), (see http://npoesslib.ipo.noaa.gov/S_cmis.htm). The SRD contains performance requirements for both the CMIS environmental data products and the sensor engineering performance requirements such as general specifications for the receiver, scanning and scene sampling systems, antenna, polarization, and sensor calibration. The CMIS performance requirements and SRD were developed by the IPO working closely with the operational and scientific meteorological communities.

CMIS is the primary source for 20 of the 66 NPOESS Environmental Data Records (EDRs) listed in Table 1. During the risk reduction or phase one development, optimization of the CMIS design was carried out by two competing industry teams through the use of a Government assigned Integrated Requirements Prioritization List (IRPL) shown in Table 2.

TABLE 1
CMIS EDR Titles And Category Listing

CMIS EDRs	Category
Atmospheric Vertical Moisture Profile (surface to 600 mb)	I
Sea Surface Winds (speed)	I
Soil Moisture	I
Atmospheric Vertical Moisture Profile (600 – 100 mb)	II
Atmospheric Vertical Temperature Profile	II
Cloud Ice Water Path	II
Cloud Liquid Water	II
Ice Surface Temperature	II
Land Surface Temperature	II
Precipitation	II
Precipitable Water	II
Sea Ice Age and Sea Ice Edge Motion	II
Sea Surface Temperature	II
Sea Surface Winds (direction)	II
Total Water Content	II
Cloud Base Height	III
Fresh Water Ice	III
Imagery	III
Pressure Profile	III
Snow Cover/Depth	III
Surface Wind Stress	III
Vegetation/Surface Type	III

TABLE 2
CMIS INTEGRATED PRIORITIZATION LIST (IRPL) FOR THE RISK REDUCTION PHASE DEVELOPMENT

Priority	CMIS EDR Category or Attribute
1	Category I EDRs
2	Category II EDRs/Cost
3	Volume
4	Category A EDRs/Mass
5	Power
6	Category III EDRs
7	Category B EDRs
8	Data Rate

The attributes of the highest priority EDRs determined the key design attributes such as the CMIS aperture, channelization, scan and sampling, calibration accuracy, redundancy and others. The CMIS is designed to improve the resolution, measurement range, sensitivity and accuracy of most heritage operational EDRs such as sea surface wind speed, precipitation and cloud EDRs. CMIS is also anticipated to be the first to deliver several EDRs operationally such as sea surface wind direction, sea surface temperature, soil Moisture, and cloud base height.

3. CMIS SENSOR CHARACTERISTICS

Due to requirements for improved resolution and lower frequency channels to fulfill EDR attributes, the CMIS is substantially larger than its heritage operational sensors, the Special Sensor Microwave Imager (SSM/I) and the Special Sensor Microwave Imager/Sounder (SSMIS). A view of the CMIS sensor mounted on a notional NPOESS spacecraft is shown in Figure 1.

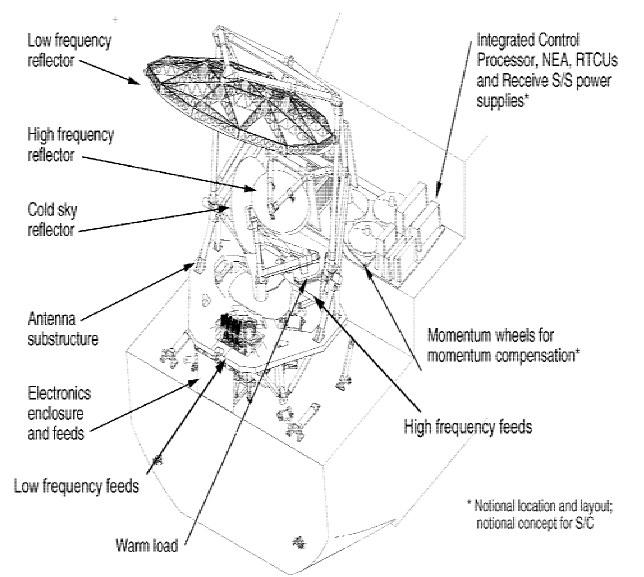

FIGURE 1.
View of the CMIS with the antenna deployed, mounted on the NPOESS spacecraft (notional view).

The CMIS utilizes a dual-primary reflector to facilitate measurements across a large frequency range from near 6 GHz to over 190 GHz. The two offset parabolic reflectors are oriented 180º apart about the vertical spin axis of CMIS. The larger reflector has an aperture of 2.2 m (effective aperture of 2.06 m) and is utilized by the lower frequency CMIS channel set (≤ 89 GHz). The smaller reflector has an aperture of ~0.7 X 0.5 m and covers the higher frequency range (above 89 GHz). The associated feedhorn clusters are positioned at two separate locations near the focal point of each reflector. However all channels are calibrated using a single warm calibration target and a single cold sky reflector, consistent with heritage conical-scanning microwave radiometers. While one channel set is observing the Earth, the other set is observing the calibration targets, resulting in each channel being calibrated once per scan.

The low frequency feedhorn cluster contains 12 separate feedhorns arranged in a 2 dimensional group centered on the focal point of the offset parabola. This results in multiple off-nadir angles of 45.4º, 47.0º and 48.7º with respective Earth incidence angles of 53.6º, 55.7º and 58.1º. The high frequency feedhorn cluster contains four feedhorns, 2 each for the 166-GHz and 183-GHz channels. Accordingly, these are arranged to provide a single off-nadir angle of 46.8º and an EIA of 55.5º. The Instantaneous Fields Of View (IFOVs) for the CMIS feedhorn and reflector arrangement are shown in Figure 2. Co-registration of the low frequency channel set IFOVs is facilitated by designing the offsets in elevation to correspond with an integral number of scans. In a similar manner, co-registration of the high frequency channels and the 50-GHz low frequency sounding channels is facilitated by introducing a small offset in elevation allowing the channels to view the same ground location one-half rotation later.

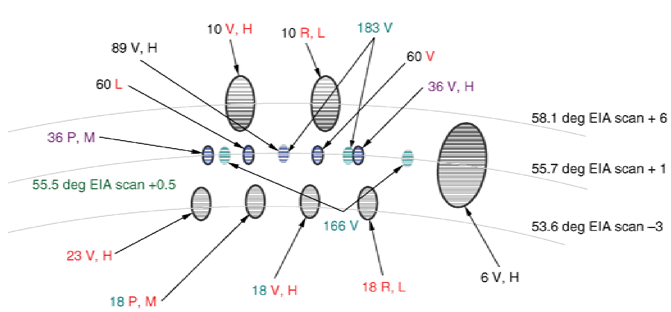

FIGURE 2.
CMIS Instantaneous Fields of View (IFOVs) for all channels showing the azimuthal offsets and Earth incidence angles.

The CMIS will have a nominal data rate of ~500 kb/s, mass of ~275 kg and will require ~340 W orbital average power. The scan rate is designed to be 31.6 RPM and the nominal orbital altitude is 833 km. CMIS is designed such that all channels are Nyquist-sampled in the along scan direction. The cross-scan direction is also Nyquist-sampled except for the region ~±20° from the center of scan (along track direction). The CMIS sensor is designed for greater than 0.9 reliability after 7 years on-orbit including an 8-year storage (total of 15-year mission lifetime). The design has substantial redundancy to eliminate critical single point failures.

4. Polarimetric Measuremets

In support of the sea surface wind direction EDR, CMIS performs brightness temperature measurements at several precisely-determined polarizations at 10.65, 18.7 and 36.5 GHz as listed in Table 3. To help assure that polarization characteristics of these measurements are precisely known and maintained, a separate feedhorn at each frequency and for each dual-orthogonal polarization pair is used. The feedhorns are arranged so that identical Earth incidence angles are maintained for each frequency (see Figure 2).

TABLE 3
CMIS Polarimetric Channels

Channel Name	Polarization*	Center Frequency (GHz)	Bandwidth (MHz)
10V,H,R,L	VHRL	10.65	100
18V,H,P,M,R,L	VHPMRL	18.7	200
36V,H,P,M	VHPM	36.5	1000

*Polarizations: V=vertical, H=horizontal, P=linear +45º, M=linear -45º, R=Right Circular, L=Left Circular.

Precision knowledge of the CMIS antennas cross-polarization characteristics is needed because of the sensitivity to polarization mixing in performing sea surface wind measurements. Extensive analyses were carried out during the phase one study to ensure the polarized CMIS brightness temperature measurements could be adequately calibrated to enable sea surface wind direction retrieval.

5. FFT Sounding Channels

An important aspect of CMIS is its moisture and temperature sounding capability. CMIS has 9 channels in the 50 – 60 GHz region that were selected to support the Atmospheric Vertical Temperature Profile (AVTP) EDR requirements below ~20 mb. These channels have center frequencies from 50.3 – 59.94 GHz. For a complete listing of the CMIS analog channel set see [1]. CMIS is also required to measure AVTP up to 0.01 mb at reduced spatial resolution. This is primarily achieved by a set of 40 channels within a 20-MHz bandwidth centered near 60.434776 GHz (7+ O_2 line) as listed in Table 4. The individual channels in the FFT set (60LFFT) vary in bandwidth from 1.5 MHz at the edges to 250 kHz at the center of the range. The channel characteristics are determined through sampling of the bandwidth and application of a Fast Fourier Transform (FFT) process. The FFT channels are augmented by 4 additional analog channels centered near the 7+ absorption line (see [1]).

TABLE 4
CMIS FFT Sounding Channels

Channel Name	Polarization*	Center Frequency (GHz)	Bandwidth (MHz)
60LFFT (entire BW)	L	60.434776	25
60LFFT 1,40			1.5
60LFFT 2,39			1.25
60LFFT 3,4,37,38			1.00
60LFFT 5,36			0.75
60LFFT 6-8, 33-35			0.50
60LFFT 9-32			0.25

*Polarizations: L=Left Circular

The conical-scan geometry of CMIS results in varying Doppler shift as a function of the scan line-of-sight with respect to the velocity vector of the spacecraft. Compensation for Doppler is accomplished by appropriate selection and weighting of channels within the sampled bandwidth. Therefore, removal of channel-to-channel biases within the FFT suite of channels is critical to maintain uniform brightness temperature measurements over the CMIS swath.

6. Summary

The CMIS sensor baseline design developed over the risk reduction period, effectively integrates many features of heritage conical-scanning radiometers into the design of a single radiometer. Covering a frequency range from 6.6 to over 190 GHz with polarimetric and narrowband digital FFT measurement capability, CMIS will offer several new operational products (sea surface wind direction, soil moisture, and cloud base height), and quantifiable resolution and measurement range improvements over existing remotely-sensed environmental products. The CMIS phase two development also presents many technical challenges, particularly in the area of antenna characterization, sensor calibration, and signal and data processing.

The authors would like to thank Boeing Satellite Systems for providing depictions of the CMIS radiometer and its instantaneous fields of view.

Reference

[1] Kunkee, D. B., N. S. Chauhan, J. J. Jewell, "Spectrum Management for the NPOESS Conical-scanning Microwave Imager/Sounder (CMIS)," accepted for presentation at the 2002 IEEE IGARSS.